DUAL-TUNED 1H/13C ORTHOGONAL DOUBLE SOLENOID VOLUME COIL FOR SIMULTANEOUS ACQUISITION IN SMALL ANIMALS IN VIVO

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Introduction

Dual-tuned radiofrequency (RF) volume coils have a variety of applications in Magnetic Resonance Imaging (MRI) including spectral shimming and functional/anatomical registration. Conventional dual-tuned RF coil designs make use of trap circuits which are typically lossy at lower frequencies such as the ^{13}C frequency [1]. Furthermore, robust dual-tuned RF volume coil design remains challenging due to coupling of undesired resonant modes. Solenoid coil designs can provide high signal to noise ratio (SNR) and good B1 homogeneity [2]. However, the geometry of the solenoid design is unfavorable for transverse magnetization detection in horizontal bore pre-clinical and clinical scanners. To address this limitation we extend the concept of Orthogonal Double Solenoid (ODS) volume coil design [3] that can (1) be placed coaxially within the bore of a horizontal small animal scanner and (2) preserve ^{13}C sensitivity and ^{1}H SNR at high field.

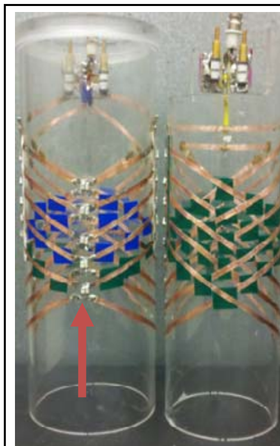

Figure 1: Double solenoid linear volume coils: H1 on the left and the C13 coil on the right. Electrical tape is used to prevent shorting.

Design

The modified solenoid coil design exploits geometry to decouple the ^{1}H and ^{13}C transmit/receive (Tx/Rx) coils. The ^{1}H and ^{13}C coils each consist of two orthogonal windings with five turns per winding spaced 1 ½ cm apart. Each solenoid is wound such that its axis is 45º with respect to the coil axis and consists of two component solenoids driven at 0º relative phase to produce a transverse B1 field [Figure 1]. Both coils are nested and rotated 90º with respect to each other. Linear polarization is achieved simultaneously on both channels orthogonal to each other. ^{13}C SNR is typically lower than that of 1H SNR due to its low natural abundance and gamma, 1.1% and $\gamma_C=1/4\gamma_H$ respectively. With this consideration, the ^{13}C coil is situated closest to the sample to improve SNR. The ^{1}H coil is placed a sufficient distance from the ^{13}C insert to minimize any remaining geometric coupling and satisfy the specifications of the scanner bore size.

Our implementation of the coil design has three independent components: an RF shield (simple copper mesh), ^{1}H Tx/Rx coil, and a ^{13}C Tx/Rx coil. All components are made on cast acrylic tubes which can be nested within each other similar to that of traditional Russian nesting dolls such that the inner tube can be replaced to allow dual tuned imaging with other nuclei. Acrylic tubes are 250 mm long, 6.35 mm thick, and with other diameter dimensions of: 107.95 mm (RF shield), 95.25 mm (^{1}H coil), and 82.55 mm (^{13}C coil). The coil is tuned for a 4.7 T Varian pre-clinical MRI (Varian, Palo Alto, CA, USA), the Larmor frequency of ^{1}H and ^{13}C are 199.75 MHz and 50.235 MHz respectively. To accommodate the high ^{1}H Larmor frequency additional components are needed to limit radiative losses. Specifically, capacitors must be added to the junctions where the solenoid conductor elements overlap as indicated in Figure 1by the red arrow such that the virtual ground placement is secured. Capacitors are chosen to series tune the coil to limit unwanted electric fields and maximize the SNR. Capacitor values were matched along the coil's axis of symmetry to achieve good B1 homogeneity. Additionally the input and output feeds were both balanced, and a lattice tune and match network was used. S21 measurement between the ^{1}H and ^{13}C element is -38 dB at the proton frequency; which confirms the coils are decoupled from each other. Two versions optimized separately for mouse and rat imaging were constructed using the identical design.

Methods

All experiments used both ODS coils concomitantly. Phantom experiments were initially completed with a spin echo acquisition (TR=250 ms, TE=16.98 ms, 256x256, 50 mm^2 FOV, slice thickness=2mm) for performance validation; a sphere saline phantom for ^{1}H and a urea syringe for ^{13}C. Preliminary experiments of anatomical images (gradient echo sequence, TR=30 ms, TE=5 ms, flip angle=20º, average=1, 128x128, slice thickness=5 mm) were acquired with a small 150 g rat with the mouse coil version. ^{13}C polarization for the *in vivo* experiment was performed using a DNP polarizer (HyperSense®, Oxford Instruments, Tubney Woods, Abingdon, Oxfordshire, UK).

Results

Phantom experiments demonstrated good homogeneity [Figure 2] and an SNR of 17.52 for the ^{1}H coil. The SNR value for the ^{1}H coil is not exceptional, but is sufficient for good anatomical images and spectral shimming goals. Spectral representation for the ^{13}C element is strong with a line width of 14.1 hertz and an SNR of 112.7 [Figure 3]. Preliminary results with a simultaneous acquisition [4]of a proton image and images of lactate and pyruvate metabolites in a small 150 g rat *in vivo* are shown in Figure 4 demonstrating the feasibility of the ODS coil design.

Conclusions

The feasibility is demonstrated for a dual-tuned ^{1}H /^{13}C orthogonal double solenoid coil that can be placed coaxially within the bore of a small animal scanner for simultaneous acquisition of multiple nuclei. Improved SNR and B1 homogeneity combined with the versatile insert design that potentially allows imaging other nuclides, such as sodium, phosphorus, etc. make this RF coil an attractive choice for dual-tuned imaging applications.

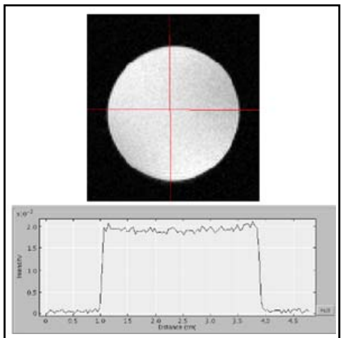

Figure 2: Transverse signal profile acquired with rat ^{1}H/^{13}C ODS coil with gradient echo using saline phantom.

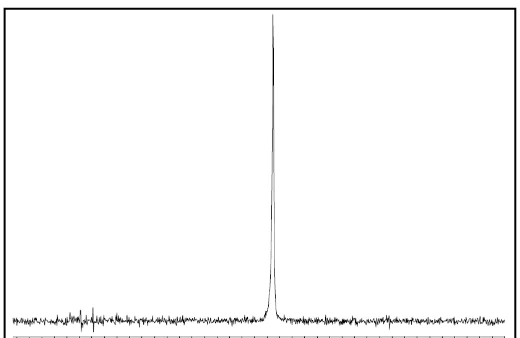

Figure 3: ^{13}C imaging spectrum acquired with rat ^{1}H/^{13}C ODS coil with peak at 163 ppm, line width = 14.1 Hz, and SNR = 112.7

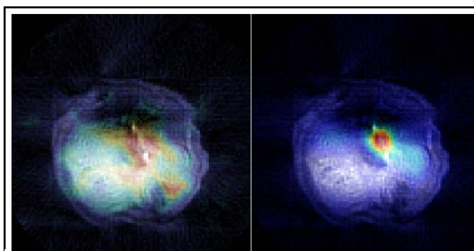

Figure 4: An example of simultaneous acquisition in vivo of ^{1}H and ^{13}C-pyruvate in a 150-g rat using the dual-tuned ODS coil. The proton image is acquired at the same time point with the lactate (left) and pyruvate (right) signals.

Acknowledgements: Thanks to GE Healthcare, Department of Radiology-UW Madison, and the Coulter Foundation for funding.

References: [1] Shen G.X. *et al*, MRM (2005), v38, 717-724, [2] Doty F.D. *et al*, NMR Biomed (2007) 304-325 , [3] Kurpad K.N., submitted to ISMRM 2011, [4] Peterson, E.T., et al., Abstract #449.ISMRM, 2010.